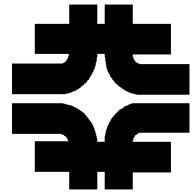
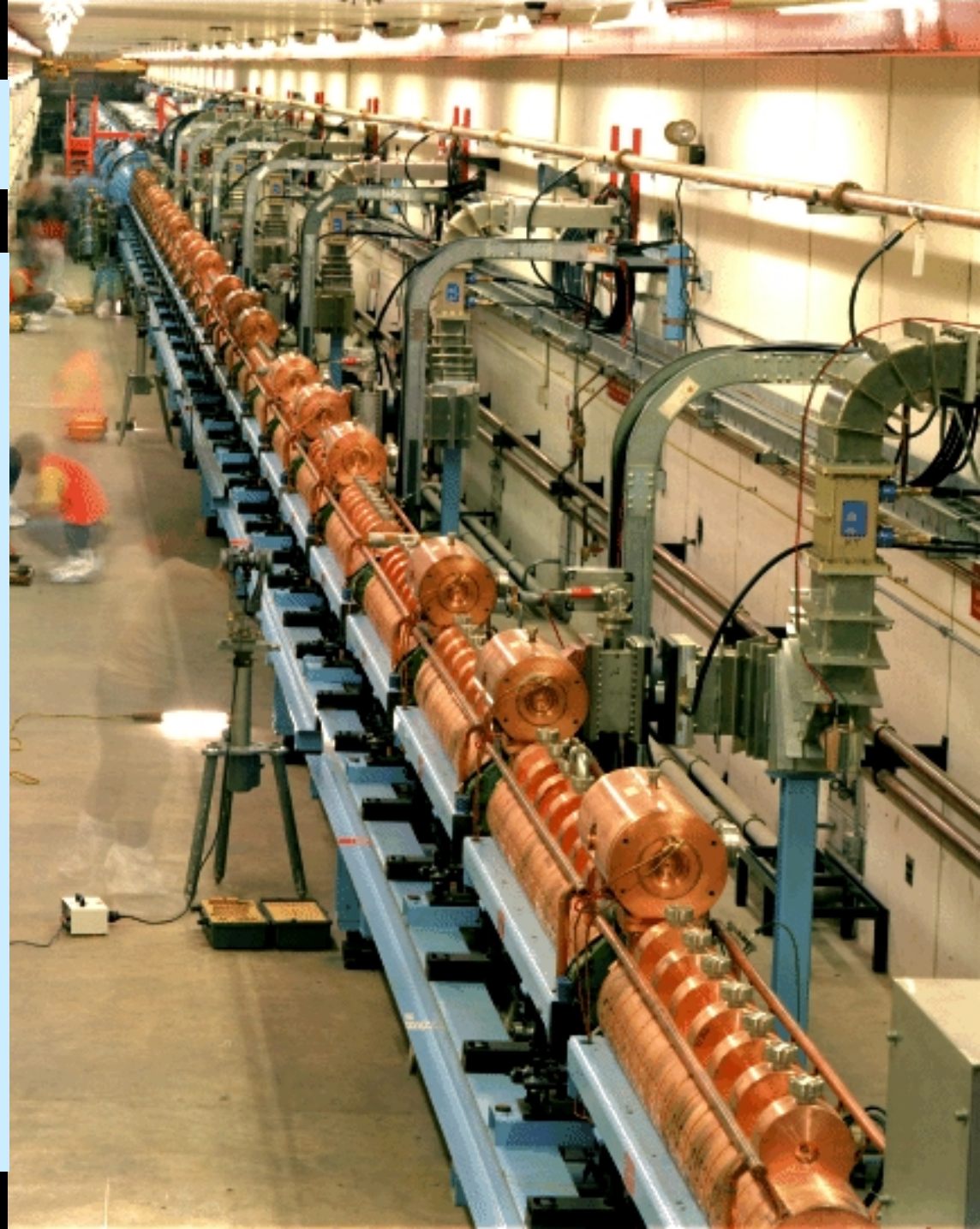


Linac Operations

Elliott McCrory
Fermilab
March 29, 2005

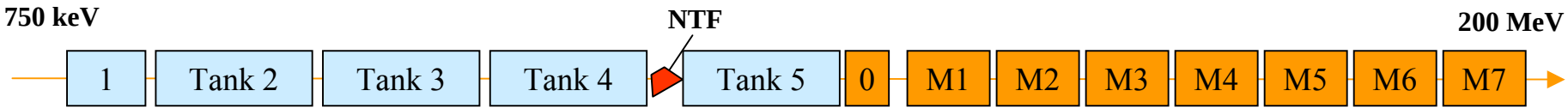
Outline

- The Fermilab Linac
- Beam Operations
  - # beam pulses
  - Beam current
  - Downtime
- Equipment Status
  - 7835 Power Amplifiers
    - *Lots of details*
  - Klystrons
  - Activation
- Conclusions



The Fermilab Linac

- 201.25 MHz Linac injects into 805 MHz Linac at 116 MeV
  - Transition section is 4 m long
    - *16-cell "buncher" cavity*
    - *3-cell "vernier" cavity*
- Seven accelerating modules with 4 sections each
  - 3 βλ / 2 between sections

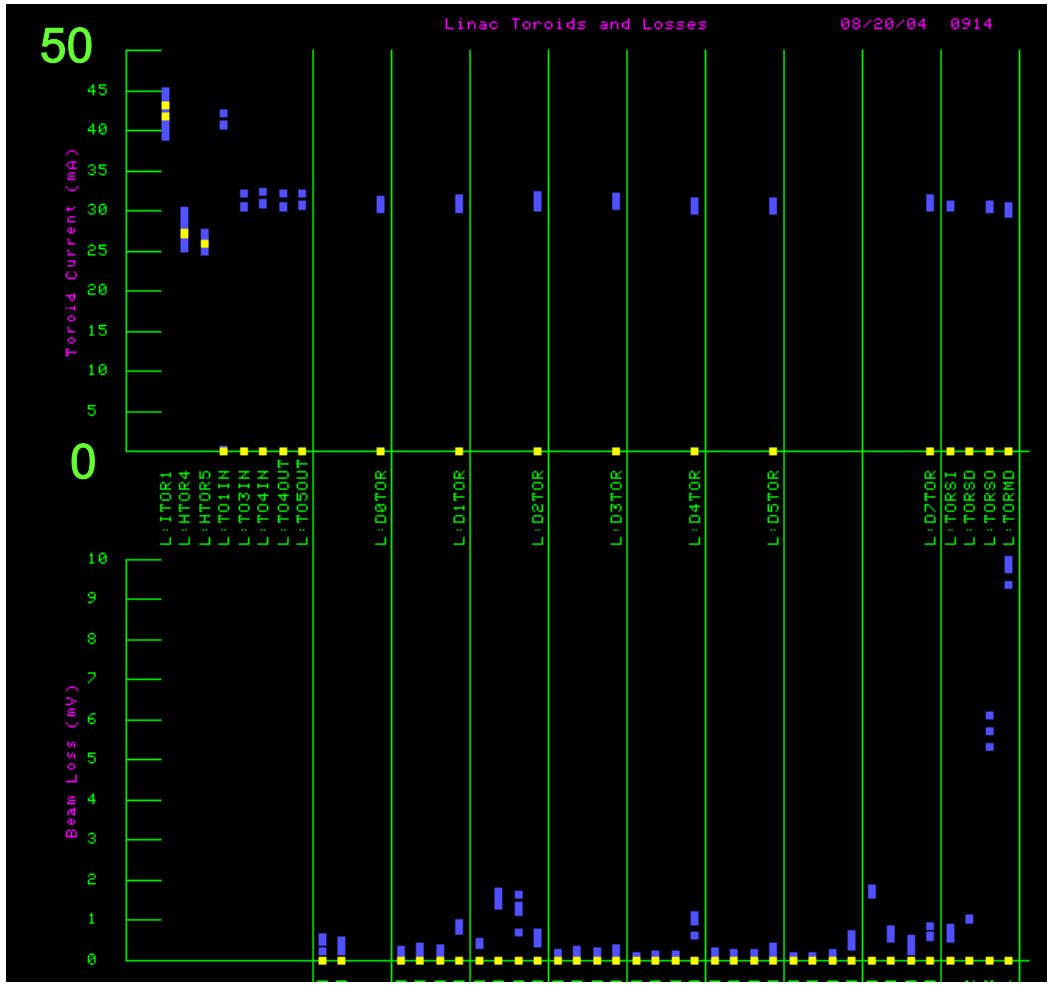


  - 2/3 of the way to Booster
- Charge-exchange injection into Booster
  - Today: 10-15 "turns" injection
  - 2.2 μsec per turn
- NTF Patient Treatment has returned

Control Room Comfort Plot

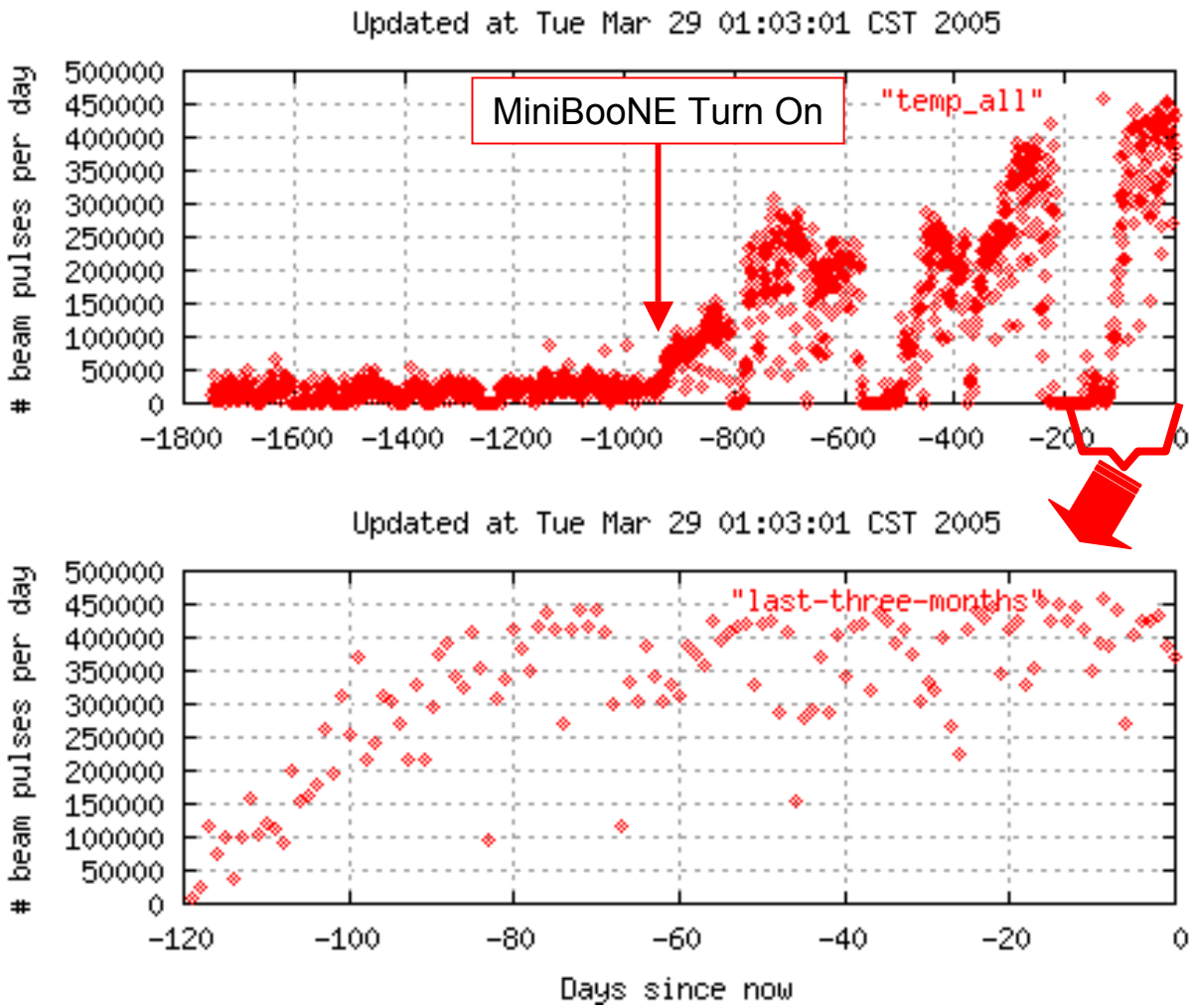
Beam Current [mA]

Particle Losses [arbitrary units]

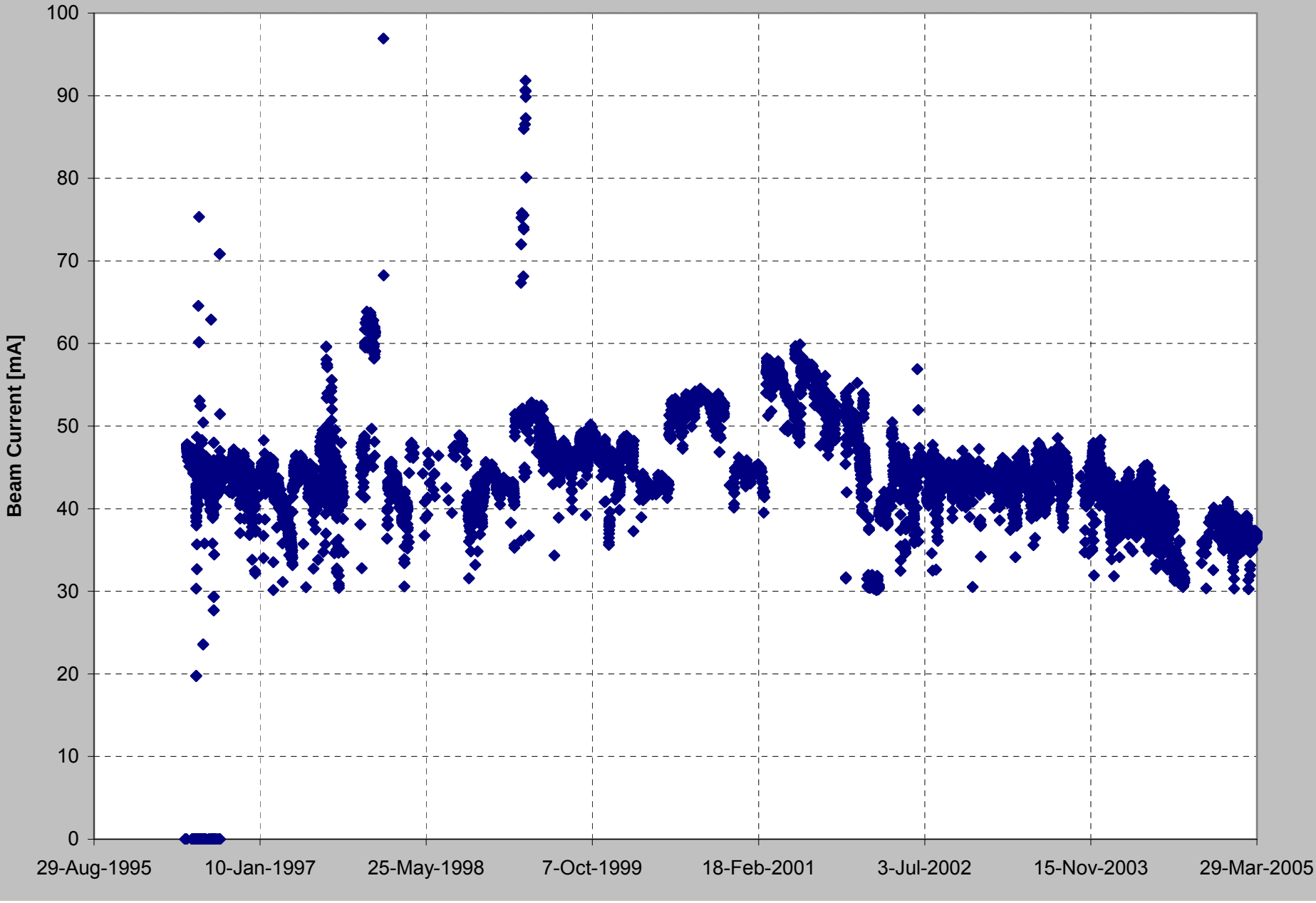


Position along Linac

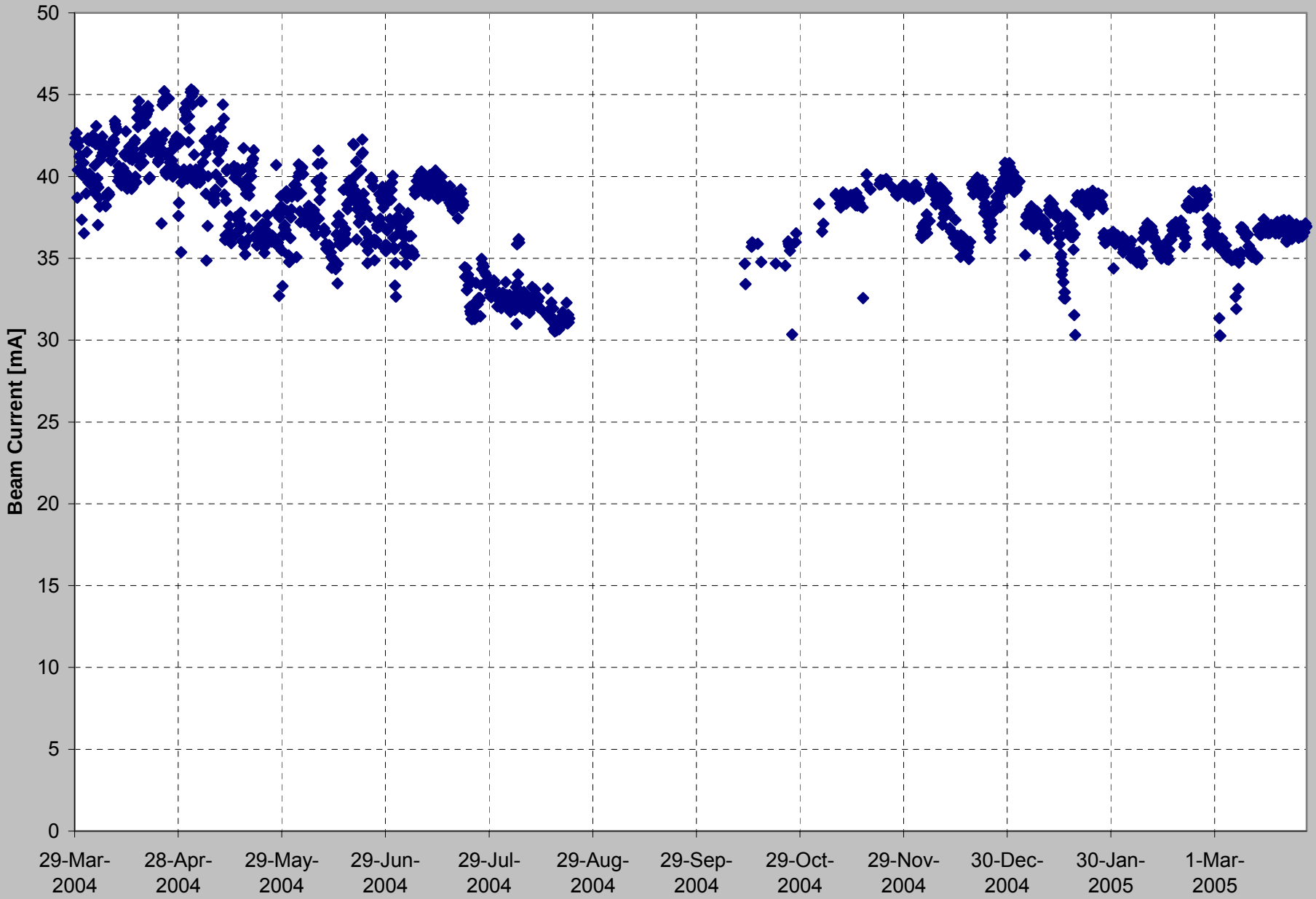
Number of Beam Pulses to Booster



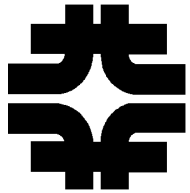
Beam Current History: Since 1986



Beam Current: Last Year

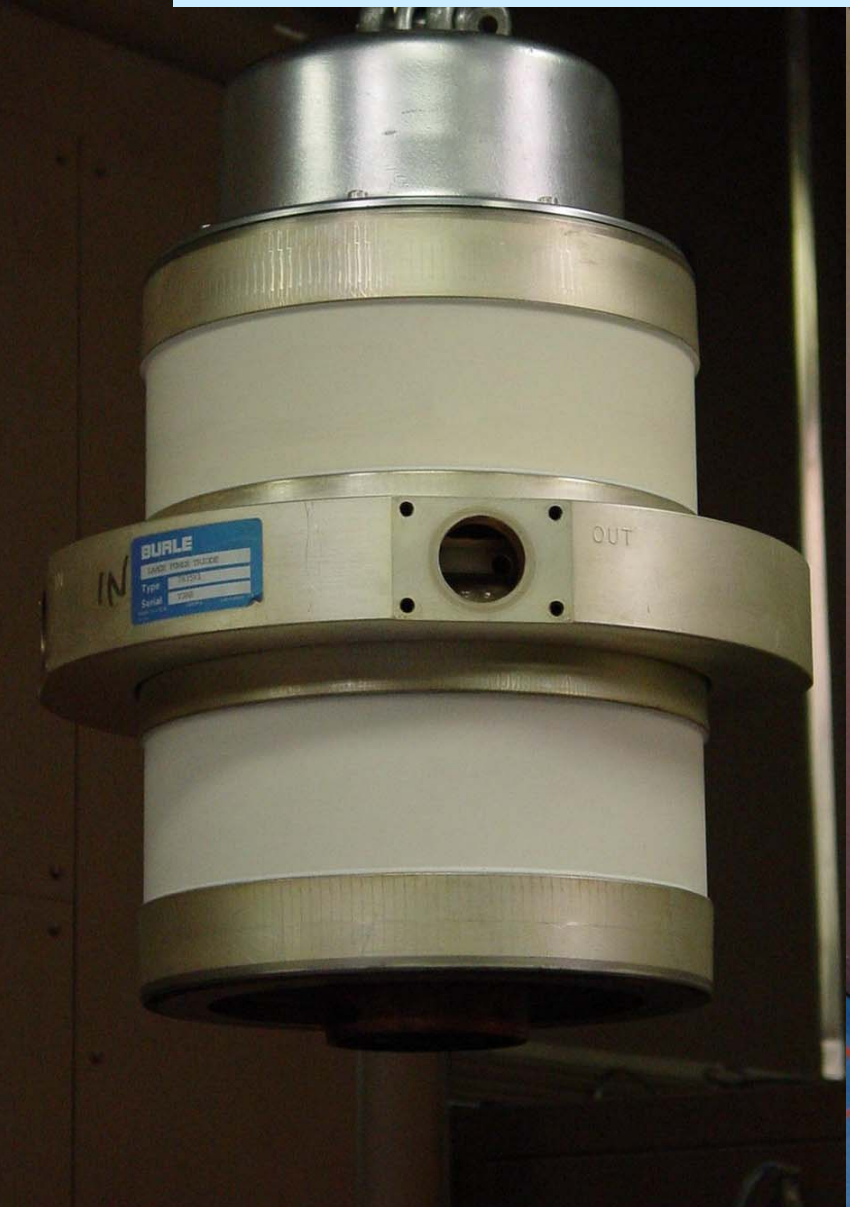


Downtime Since June, 2003



- Total: *1002 hrs / 30512 hrs* = 3.28%
  - MTBF = 295 minutes
  - Average Duration = 8 minutes
    - *RMS Duration = 28 minutes*
- Low-Energy half of the Linac: 1.19%
  - Each LRF system ~0.23%
- High-energy half of the Linac: 1.11%
  - Module 1, December 2003: 120 hours (0.39%)
  - Otherwise, each KRF system ~0.10%
- Everything else: 0.98%
  - Pre-accelerator: 0.29%
  - Quad Power Supplies: 0.20%
  - Water: 0.24%
  - Vacuum + Controls + Safety + “MISC” = 0.25%

The 201 MHz, 7835 Power Amplifier



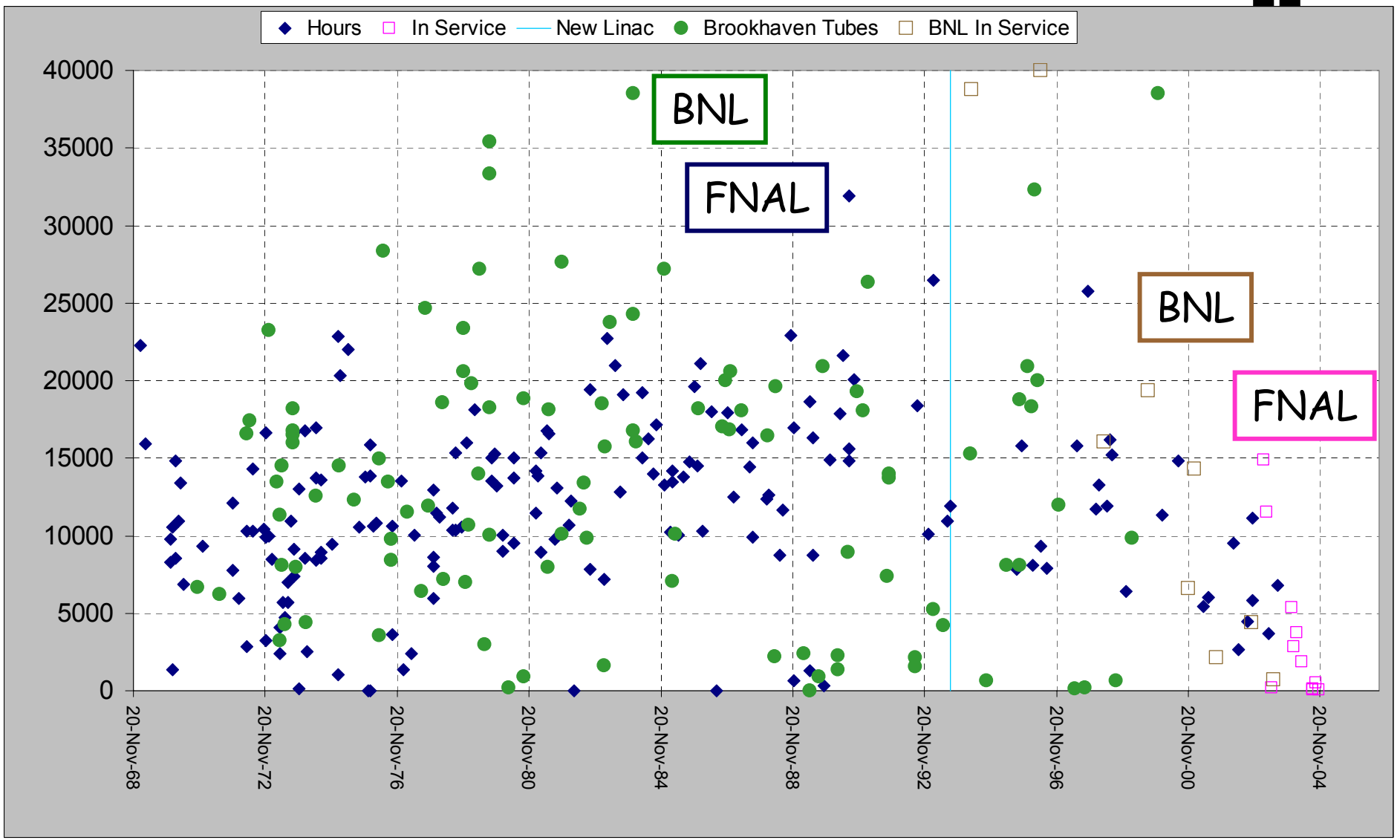
7835 PA Comments

- Tough time with manufacturer since 2000
  - Burle Industries, Lancaster, PA
    - *Several tubes have failed at less than half of the expected life*
      - *Bad filament material and other problems*
    - *Bad "getter" materials*
    - *Retirement of key experts*
      - *Anode bakeout temperature example*
  - We borrowed 3 tubes: From BNL and ANL
    - *Have repaid BNL; working on ANL repayment*
- Roger Dixon formed a "7835 Task Force" early this year
  - Phase 1 & Phase 2

7835 Task Force

- Task Force Personnel
  - EM, R. Andrews, B. Baller, D. Carlson, P. Czarapata, Jim Morgan, R. Pasquinelli, J. Spalding,
- Phase 1: Completed
  - How can we get enough PA's to last 2 years?
    - *Created an order for 12 new tubes,*
    - *Burle agreed to aggressive delivery schedule*
      - *In parallel to "regular" deliveries*
    - *Site visit was very encouraging!*
- Phase 2: Underway
  - What if this supply really does dry up?
    - *Possibilities?*
      - *New 402 MHz low-energy Linac?*
      - *Drive existing 201 MHz tanks with two, lower power tubes?*

Tube Life: FNAL & BNL



3 Labs; 3 Slightly Different Linacs

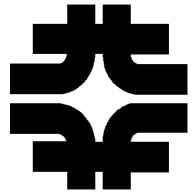
Item	FNAL	LANL	BNL
Beam Duration	30 μsec	1000 μsec	500 μsec
Repetition Rate	15 Hz	120 Hz	7.5 Hz
→Beam Duty Factor	0.06%	12%	0.4%
Peak Power	4.5 MW	2.9 MW	3 - 4.5 MW
Peak/Ave Current	40 mA / 0.024 mA	15 / 1.8 mA	
Sockets	5	4	9*
Hours/year	8000	7000	4000
Tube Lifetime	11,000 Hours		15,000 Hours

* BNL operations: Two modes
  - Isotope production
    - *35 mA, 116 MeV beam,*
    - *Drift through tanks 6, 7, 8 and 9*
  - Polarized Protons

- LANL
  - Rarely see emission limit
  - Often: Heat-related failures (Ceramics)
  - Currently: all tubes > 20000 hrs

Conclusion: Tube lifetime primarily goes as Peak Power

Comments on Beam Current



- 7835 PA vulnerability is reduced as peak beam current falls
- Have reduced current from 58 mA to 38 mA
  - Motivated by reducing loss per proton in Linac and in Booster
- Further reduction will help
  - But Booster has difficulty re-tuning to different Linac peak current
    - *Lower peak current → more Booster "turns"*

How Many Tubes ...

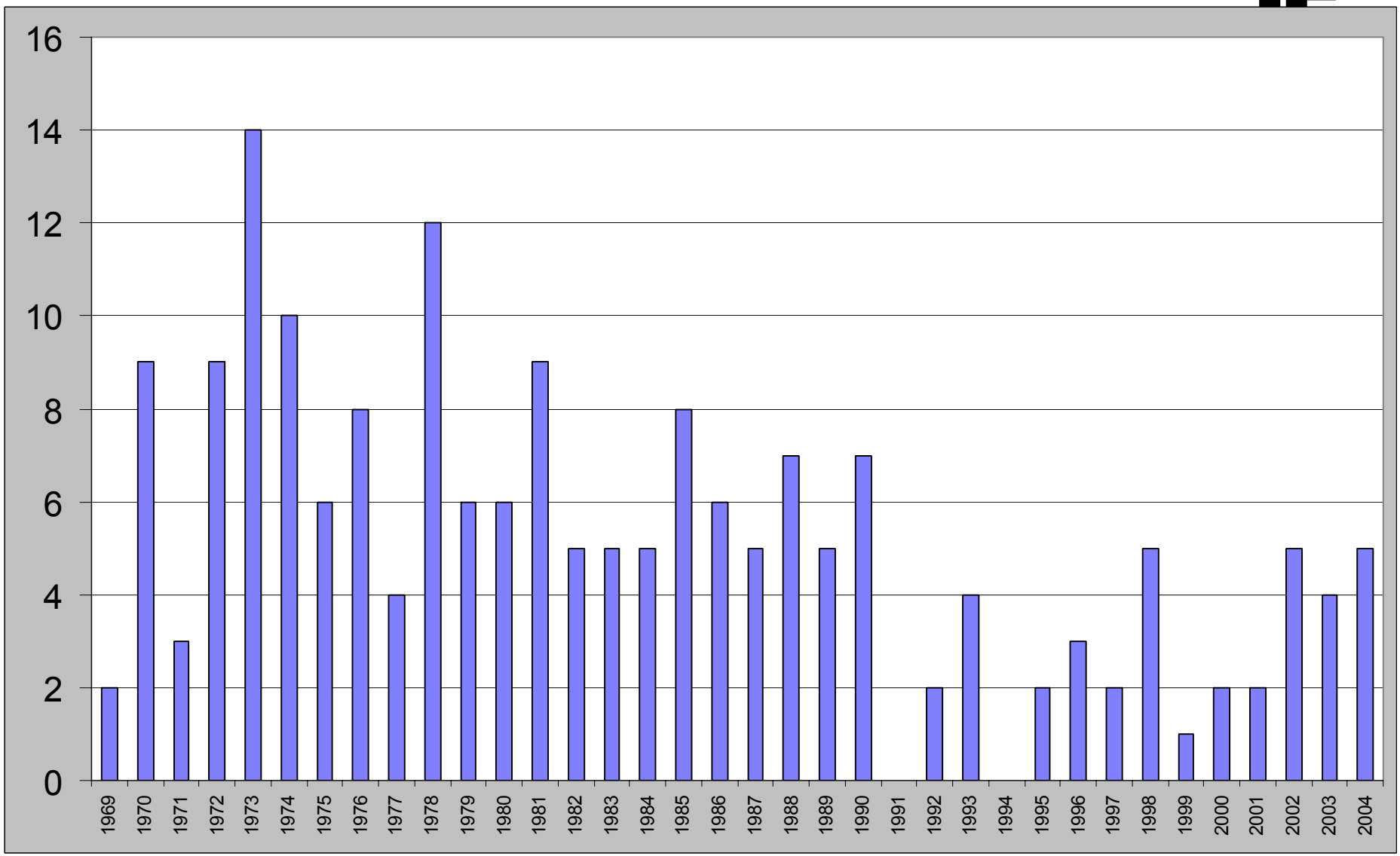
- Do we burn up?
  - For Historical lifetimes (11,000 hrs/tube)

    →3.2 ± 1.1 per year
    - *Error bar = 3*(Statistical RMS/√N)*
  - For 2001-2004 lifetimes (6000 hrs/tube)

    →5.7 ± 3.4 per year
  - Worst case (3000 hrs/tube)

    →11.0 ± 13.1 per year
- Have we received? ...

New & Rebuilt Tubes Received/Year



7835 PA Status: In Service & Spares

Sta	Tube S/N	Grad	Fil	Hours	*Days*	Fraction of median life
1	N49R6	**1.01**	**6423**	**8845**	***368***	**0.56**
2	N16R8	**1**	**6659**	**6304**	***262***	**0.58**
3	BH4	**0.98**	**6722**	**2838**	***118***	**0.26**
4	A2R4	**0.96**	**6633**	**3801**	***158***	**0.35**
5	A30R6	**0.99**	**6791**	**4695**	***195***	**0.43**
7	*N14R7*	***-0.02***	***181***	***153***	***6***	***0.01***

- BH5
  - 160 hours
- S10R7
  - 516 hours
- BK1
  - 214 hours
- A27R6
  - 11542 hours
- N27R8
  - 76 hours
- AZ4R1
  - 344 hours

7835 PA Delivery Schedule

Existing New/Rebuild Schedule			
Tube	**Delivery**	**Status**	**Owner**
A20R8	April	Task 11	FNAL
New	May		ANL
P7R9	June 05	Task 11 & 17	FNAL
New	May		FNAL
New	June		FNAL
New	June		FNAL
New	July		FNAL
BK3R1	July?	Task 6	FNAL
A1R9	October?	Task 17	FNAL

Bulk Order of new tubes, 3/1/05	
Estimated Delivery Date	**Owner**
October	FNAL
October	FNAL
November	FNAL
November	FNAL
December	FNAL
December	FNAL
January, 2006	FNAL
January, 2006	FNAL
February, 2006	FNAL
February, 2006	FNAL
March, 2006	FNAL
March, 2006	FNAL

A Typical Klystron, Installed

L3 Corporation (Litton) VKP-7955

805 MHz Klystron Issues

- Manufacturer: L3 Communications, NY, NY
  - Tubes built in San Francisco area
- Discovered a serious water issue with the design of this tube in December, 2003.
  - We thought we had 7 spares, but found that 5 were bad
  - Water-to-vacuum braise leak at collector
    - *Stagnant water in standby tubes killed them*
- L3 has redesigned collector
  - 6 tubes being rebuilt with this modification now.

Klystron Status

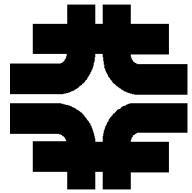
Module	Mnf	S/N	Hours	Days	Years	Internal Vacuum µA
0	Varian	L122	94569	3940	10.7	1.12
V	Varian	L113	98667	4111	11.2	0.00
1	L3	0005R1	9340	389	1	0.01
2	L3	0004	97546	4064	11.1	0.00
3	L3	0006	81918	3413	9.3	0.05
4	L3	0016	12278	511	1.3	0.09
5	L3	0007	100599	4191	11.4	0.02
6	L3	0013R1	38210	1592	4.3	0.17
7	L3	0015	82052	3418	9.3	0.65
D	Varian	A21	80967	3373	9.2	0.02

Klystron Spares & Delivery

- Varian: K107
  - 0 hours
- Varian: L026Z
  - 0 hours
- L3: 0003
  - 2194 hours
- L3: 0011
  - 37163 hours
- L3: 0002
  - 0 hours

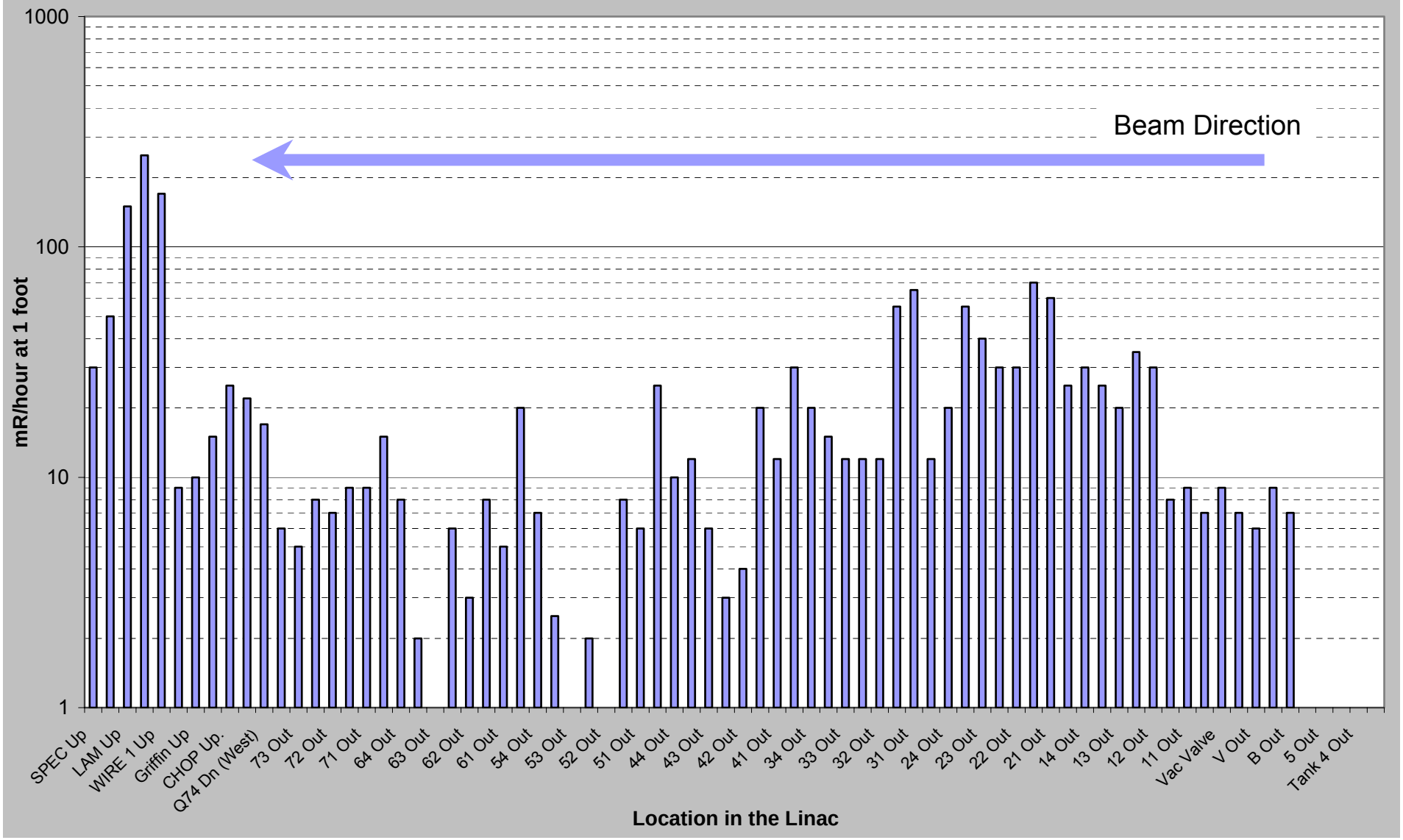
Tube	Delivery	Comments
0012	March 2005	
0009	April 2005	Water leak developed in final test
0014	April 2005	
0008R1	May 2005	
0012	March 2005	

Activation of Components

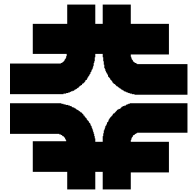


- Linac not designed for minimum losses
- What beam rate can we provide?
  - 15 Hz for ~hours
  - 5 Hz “forever”, now.
- Hands-on maintenance is possible
  - But we rarely have to!
- Smaller loss per proton at lower Linac peak current
  - For both Linac and Booster
  - Tried 58 mA; now use 38 mA.
  - May try even lower in the future.

Activation in the Linac Tunnel (at 1 Foot), March 22, 2005



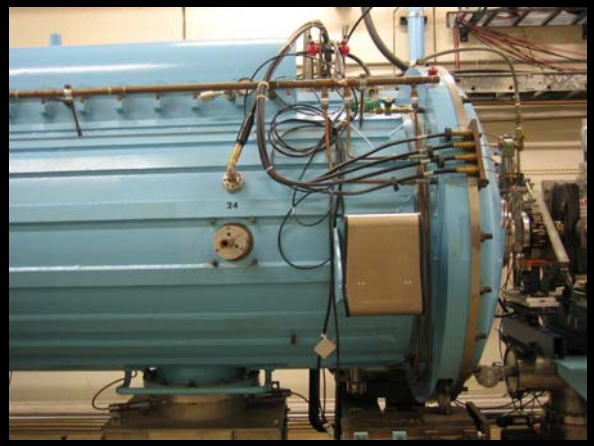
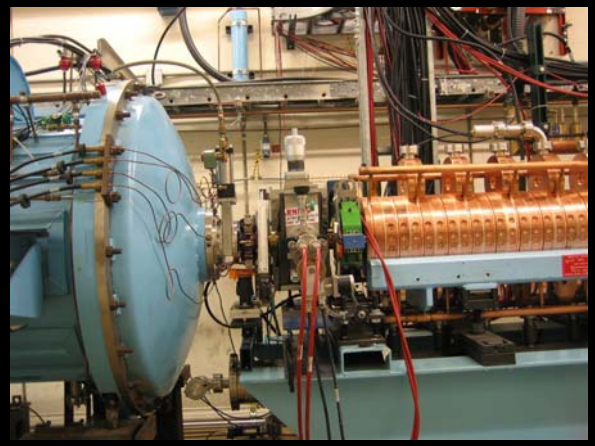
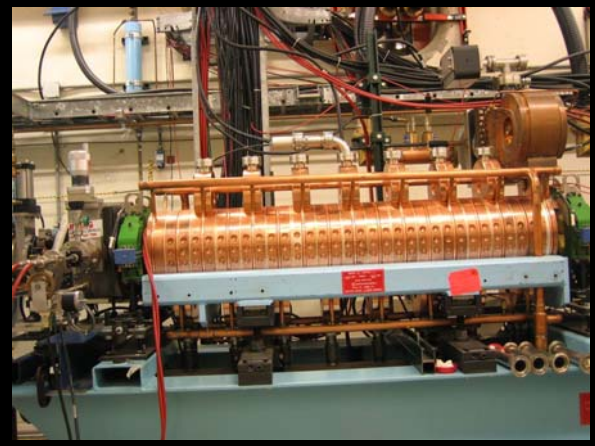
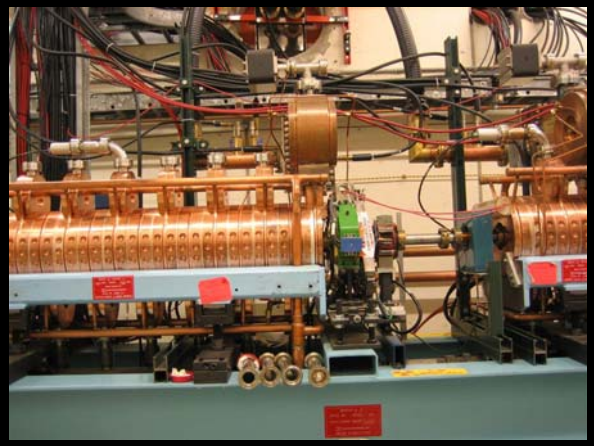
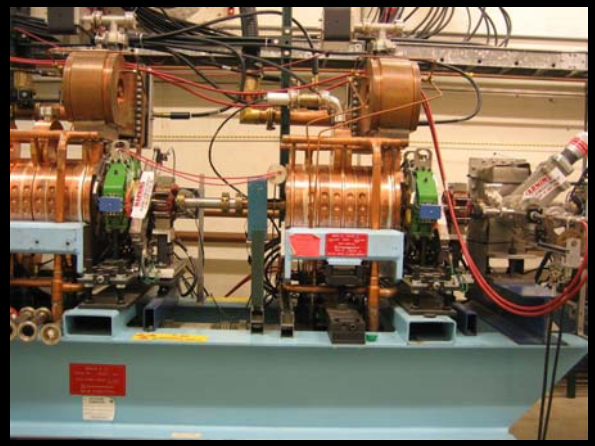
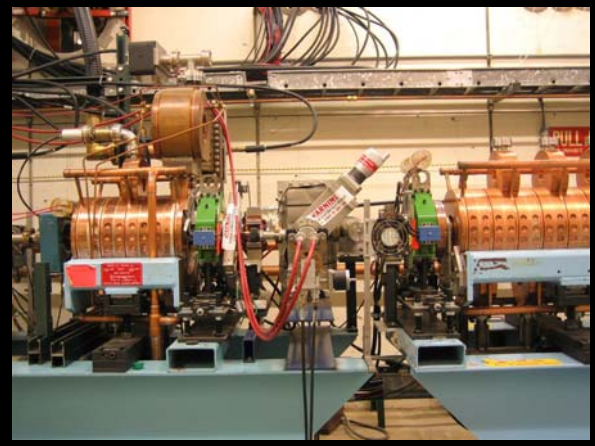
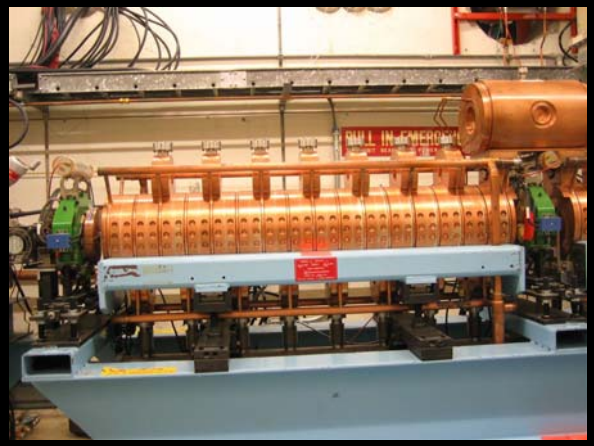
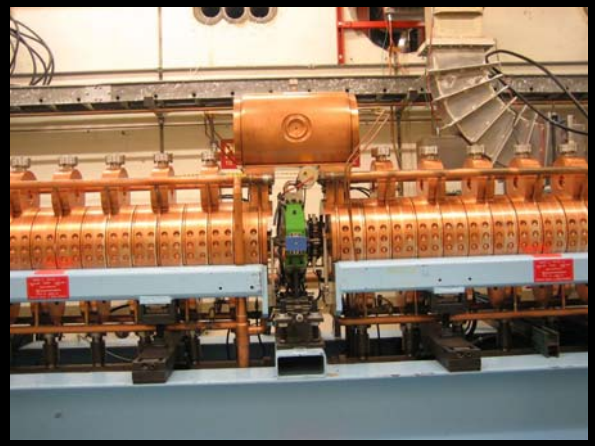
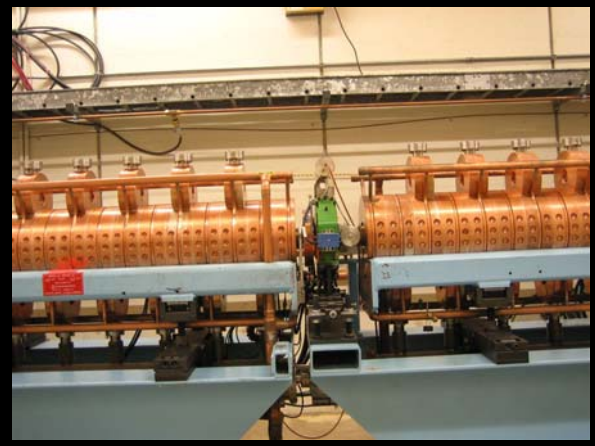
Conclusions



- The Fermilab Linac continues to be the most reliable and relied upon machine at Fermilab
  - Known problems account for most of downtime
    - *A lot of these are in the 35+ year old systems*
    - *Random failures in 805 MHz segment*
- 7835 PA issues are understood well
  - Not particularly different in severity now than it has ever been
  - Lower peak beam current might be beneficial
- We will continue to monitor tunnel activation

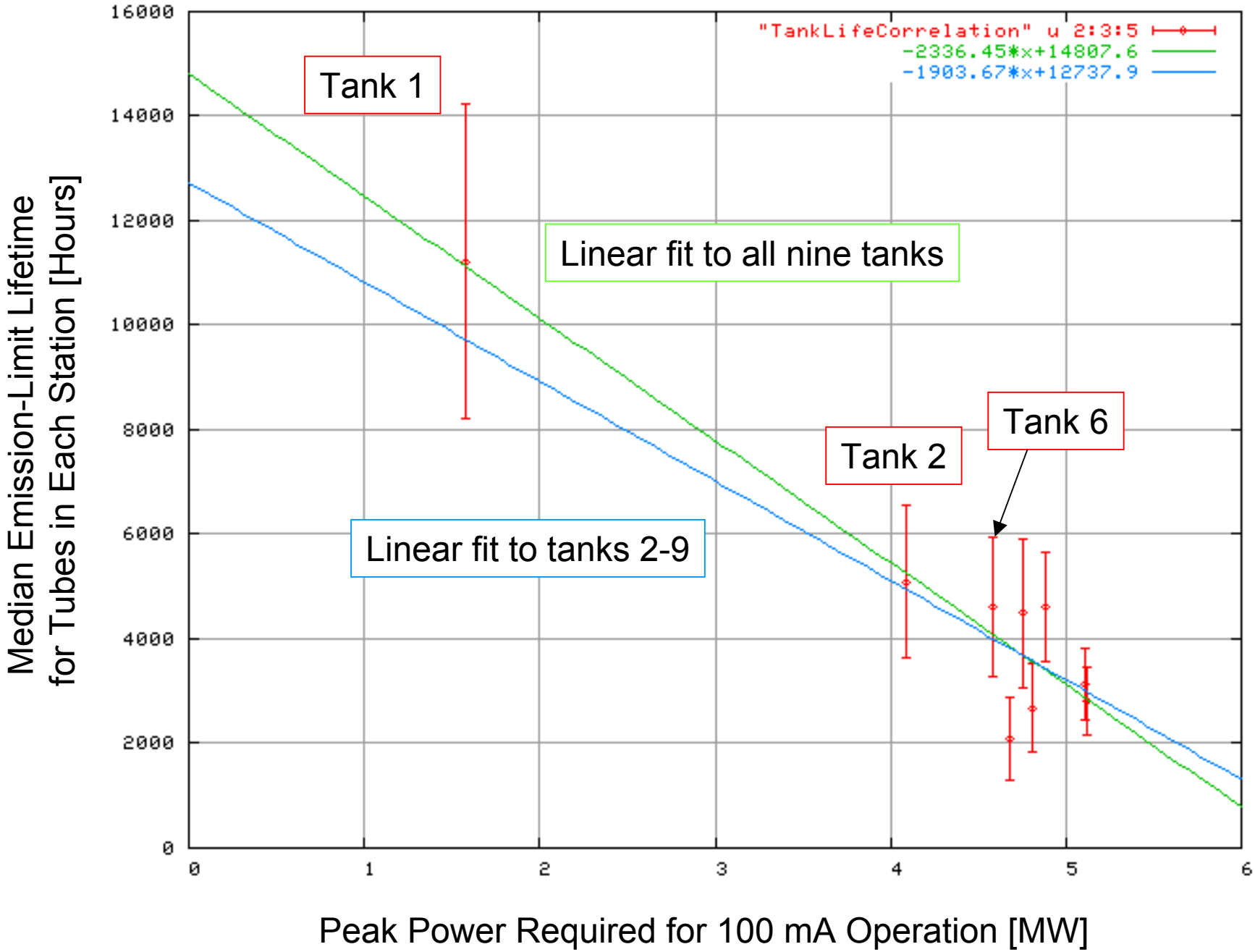
Done!

Backup Slides ...

Downtime Since 1/1/2005

--------Time--------	Duration	System	*Description of Down Time, Duration > 20 minutes*
Jan 06, 2005 04:00:00	22 min.	PACC	IHVOLT wandering.
Jan 18, 2005 16:14:00	1.00 hrs.	NTF	Linac Access for L:C32DEG cable investigation
Jan 19, 2005 10:21:00	1.06 hrs.	PACC	I- regulation/trippage
Jan 22, 2005 21:31:00	47 min.	LRF	KRF1 tripped on a switch balance indication
Jan 30, 2005 16:45:00	1.50 hrs.	PACC	I- dome motor generator brush failure.
Jan 31, 2005 14:20:00	27 min.	LRF	KRF7 temperature regulation module replacement
Feb 03, 2005 13:45:00	47 min.	LRF	KRF1 phase regulation problems.
Feb 05, 2005 17:55:00	2.00 hrs.	LPS	QPS222 tripped.
Feb 15, 2005 17:00:00	29 min.	LRF	LRF5 pulse off. PA nitrogen was low due to looses hose.
Feb 19, 2005 11:25:00	1.78 hrs.	LRF	KRF6 down CS ind. PFN crowbar, IGNT_I_ST
Feb 19, 2005 23:29:00	2.05 hrs.	LWATR	KRF6 PFN water leak.
Feb 22, 2005 08:50:00	41 min.	LPS	L:QPS130 and L:QPS229 noisy.
Feb 22, 2005 18:45:00	3.83 hrs.	LRF	QPS130 erraticaaly out of tolerance.
Feb 22, 2005 22:36:00	43 min.	LPS	QPS130 replacement underway. A rad trip at Linac TK #1 when PS was turned off
Feb 23, 2005 07:21:00	22 min.	LPS	L:QPS113 & L:QPS114 regulation problems
Feb 24, 2005 05:00:00	1.45 hrs.	LPS	QPS229 & QPS130 regulation problems.
Mar 02, 2005 03:56:00	3.73 hrs.	LRF	LRF3 tripped on a IPA2 failure.
Mar 02, 2005 06:23:00	3.25 hrs.	PACC	L:HARCI output failure and recovery.
Mar 07, 2005 15:28:00	2.13 hrs.	LMISC	KRF6 solenoid failure.
Mar 15, 2005 04:23:00	37 min.	LPS	L:SPECUR in and out of tolerance.
Mar 18, 2005 22:20:00	2.58 hrs.	LRF	KRF5 trip
Mar 23, 2005 09:06:00	1.40 hrs.	LRF	KRF7 arc over caused water leak onto equipment in the charging supply.
Mar 28, 2005 10:36:00	44 min.	LRF	KRf2, KRF3, & KRF5 water hose repair.
Mar 27, 2005 06:59:00	33 min.	LRF	KRF6 water leak repairs.
Total Down Time:	**52.31 hrs**	**2.69%**	*This is the total for all downtime. This table only shows DT>20 minutes*


"TankLifeCorrelation" u 2:3:5
-2336.45*x+14807.6
-1903.67*x+12737.9
Tank 1
Linear fit to all nine tanks
Tank 2
Tank 6
Linear fit to tanks 2-9
16000
14000
12000
10000
8000
6000
4000
2000
0
0
1
2
3
4
5
6
Median Emission-Limit Lifetime for Tubes in Each Station [Hours]
Peak Power Required for 100 mA Operation [MW]